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DEVELOPMENT OF LIGHTNING CURRENT DETECTOR

Stephen Livermore
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

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SPACE VEHICLE OPERATIONS DIRECTORATE

DEVELOPMENT OF LIGHTNING CURRENT DETECTOR

Stephen Livermore
John F. Kennedy Space Center
Kennedy Space Center, Florida 32899

CONCURRENCE:

William Jafferis
William Jafferis
Technical Assistant to
Director, Space Vehicle Operations

APPROVAL:

W. J. Kapryan
W. J. Kapryan
Director,
Space Vehicle Operations

ABSTRACT

A lightning current detector to record the maximum current amplitude of a lightning strike to the 150 meter weather tower at KSC was developed. The principle of operation of the detector is discussed, materials chosen to build the detector are described, and calibration tests performed on the detector are given. Field results of the detectors from two separate lightning strikes to the tower are included.

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DEVELOPMENT OF LIGHTNING CURRENT DETECTOR

By Stephen Livermore
John F. Kennedy Space Center

SUMMARY

The design, construction, testing, and installation of lightning current detectors on the 150 meter weather tower at KSC were implemented in this project. The current detectors are passive devices utilizing 1/4" magnetic tape with a prerecorded signal mounted to the six guy ground cables of the tower's outer guy wires. Electric current from a lightning flash to the tower will produce a magnetic field which will erase part of the recorded signal on the magnetic tape nearest the wire. Calibration tests were performed on the current detector using a high voltage generator to simulate lightning currents. These tests were performed to determine a correlation between current down a conductor and the amount of signal erased from the magnetic tape. Thirteen tests were performed to provide a wide range of current values for calibration purposes. A linear curve fit program was computed to calibrate the detectors using the experimental results of the tests. Two Rogowski coils with flashbulb attachments are mounted on the guy ground wires of the tower to provide a visual indication of a lightning flash to the tower. Two lightning strikes to the tower have been recorded since the current detectors were first installed. The maximum current amplitude of the first strike, on 7/19/76, was approximated to be 189,000 amperes while the second strike, on 8/14/76, indicated a maximum peak current of 85,600 amperes. Presently, the tower is fully instrumented with ten current detectors and two Rogowski coils.

INTRODUCTION

This report describes lightning current detectors to monitor lightning currents in the 150 meter weather tower at Kennedy Space Center. This report describes the detector development and describes the calibrations made on the completed set of detectors.

The purpose of this project is to design, construct, test, and install lightning current detectors to the 150 meter weather tower at UC 16 for monitoring of lightning strikes and recording their maximum current amplitudes (see Appendix A). The lightning detectors are required to replace the existing measuring devices mounted on the tower for continued analysis of the LEA dissipation array system.

INSTRUMENT CONFIGURATION

The instrument configuration is shown on Figure 1. The lightning current detectors designed for this project are passive devices which consist of a strip of magnetic tape with a prerecorded signal mounted in a weather protective tube perpendicular to a down conductor of the tower. These current detectors are mounted to the outer guy wire ground cables and to the top of the tower to record the peak value of the lightning current flowing down these paths. Two Rogowski coils or current sensing coils with a flashbulb attachment are also used to provide visual indication of a lightning strike to the tower.

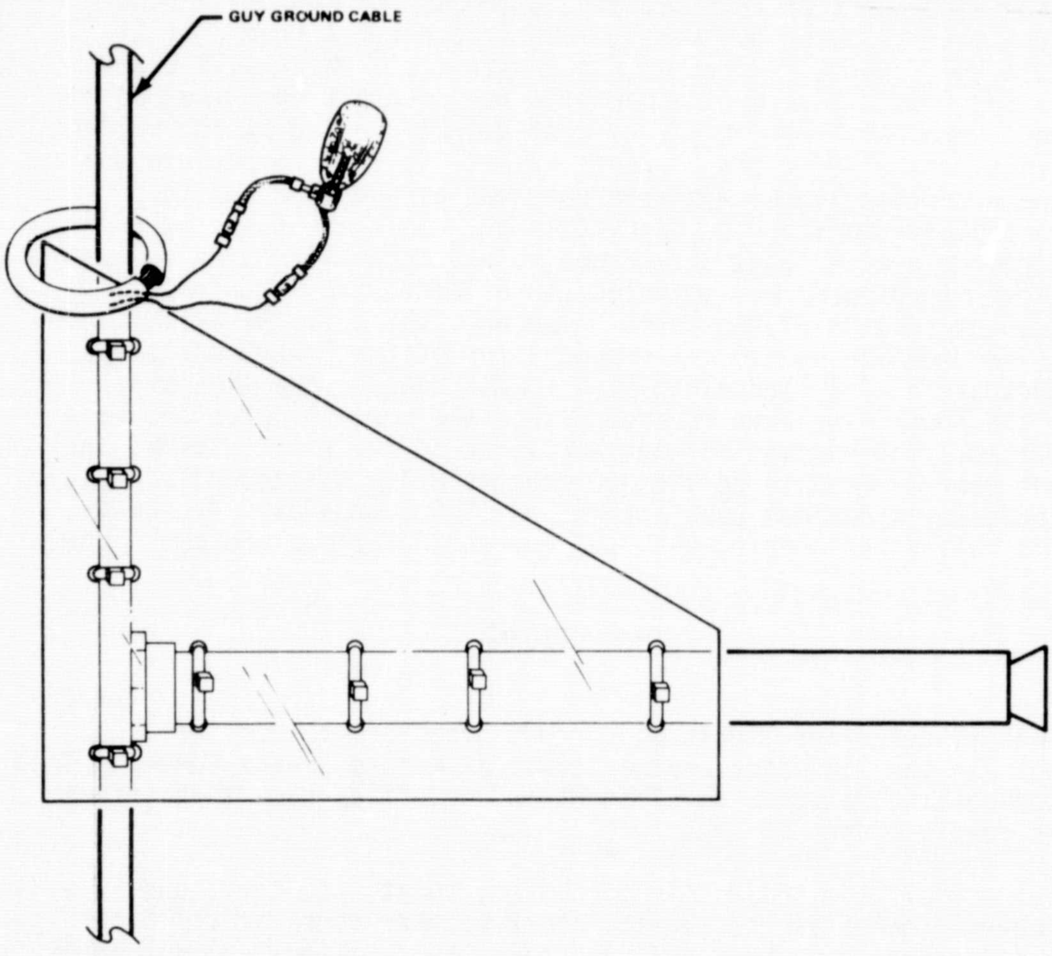


Figure 1.- Lightning current detector mounted to guy ground cable.

CURRENT DETECTORS

The principle of operation of the current detectors is that when lightning current travels down a current carrying conductor, a magnetic field will be produced which will erase a portion of the recorded signal on the magnetic tape closest to the conductor. The distance away from the conductor that the signal is erased is dependent upon the strength of the magnetic field around the conductor. The greater the peak value of the current down the conductor, the greater the magnetic field produced.

For an infinitely long straight conductor, the magnetic field strength, H, at any point away from the conductor is dependent solely upon the peak value of the current and the radial distance away from the conductor to the point.

$$H = I/2\pi r \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

These lightning current detectors will provide a measurement of the maximum peak current of the lightning flash. They will not have the capability to distinguish between the various strokes of the flash, the number of strokes, or the corresponding rise times or durations of the individual strokes in the lightning flash. Since the initial stroke of the flash usually generates the highest peak current, subsequent strokes should not affect any more of the recorded signal still left on the tape since their corresponding magnetic fields will be of a lesser intensity than the magnetic field from the initial stroke. This overlapping of successively smaller magnetic fields on the tape will reinforce that portion of the tape that was already erased from the magnetic field produced by the first stroke.

Figure 2 shows a typical current waveform of a multiple stroke lightning flash.

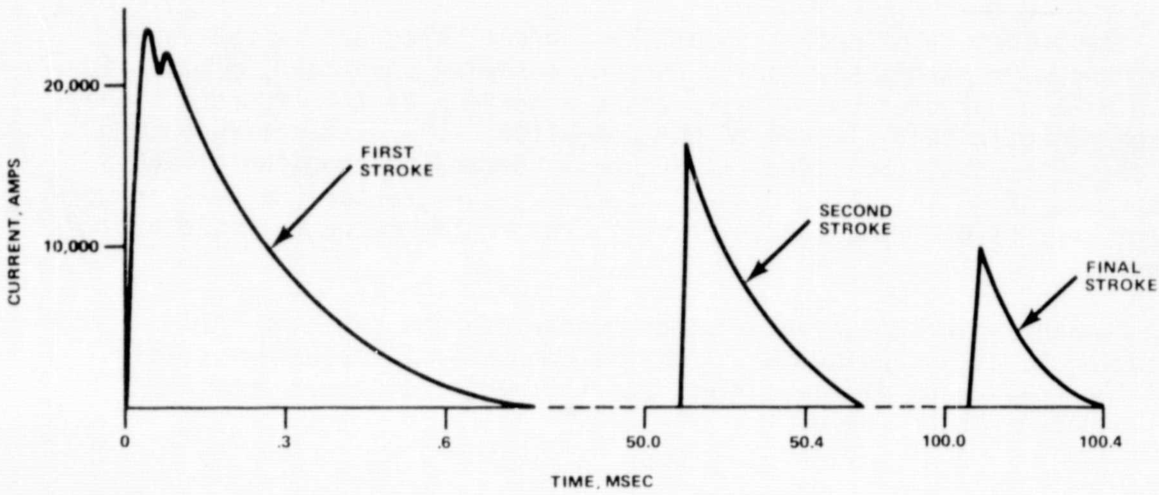


Figure. 2- Current at ground from typical multi-stroke lightning flash.

Each lightning current detector consists of:

a. Two foot length of 3/4 inch I.D. PVC tubing.

b. End cap permanently secured to one end.

c. 2' x 1/2" x 1/4" plexiglass strip mounted inside of PVC tube.

d. Four foot length of 1/4" magnetic tape with a prerecorded signal doubled-over the plexiglass strip, mounted lengthwise inside the PVC tube.

e. Rubber stopper to seal other end of PVC tube and to secure magnetic tape in a flat horizontal position (see Figure 3).

f. A triangular shaped plexiglass mounting bracket to secure the detector perpendicular to the guy ground cable.

g. Ty-wraps to fix detector tube to the plexiglass mounting bracket and the mounting bracket to the guy ground cable. Figures 4a, b, and c show the lightning current detectors mounted to the south guy wire base of the 150 meter weather tower.

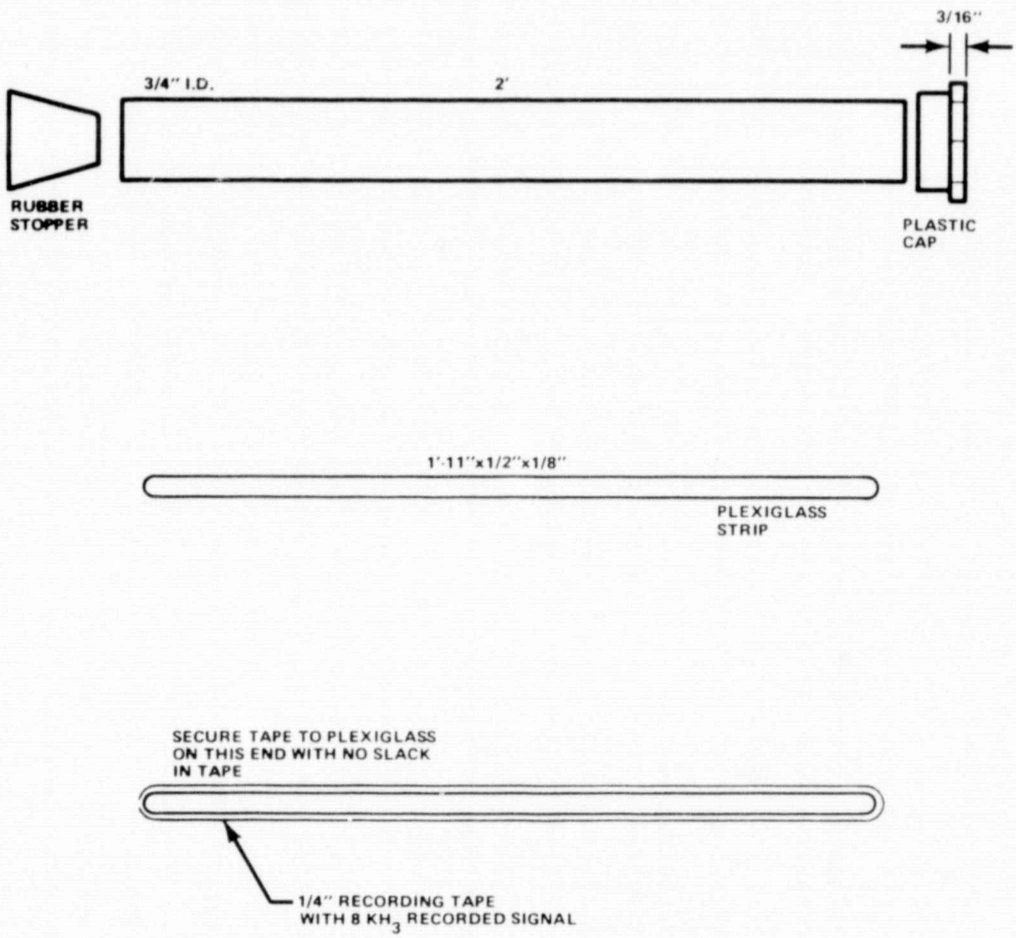


Figure 3.- Components of lightning current detector.

Figure. 4a- Current detectors and guy ground cables.

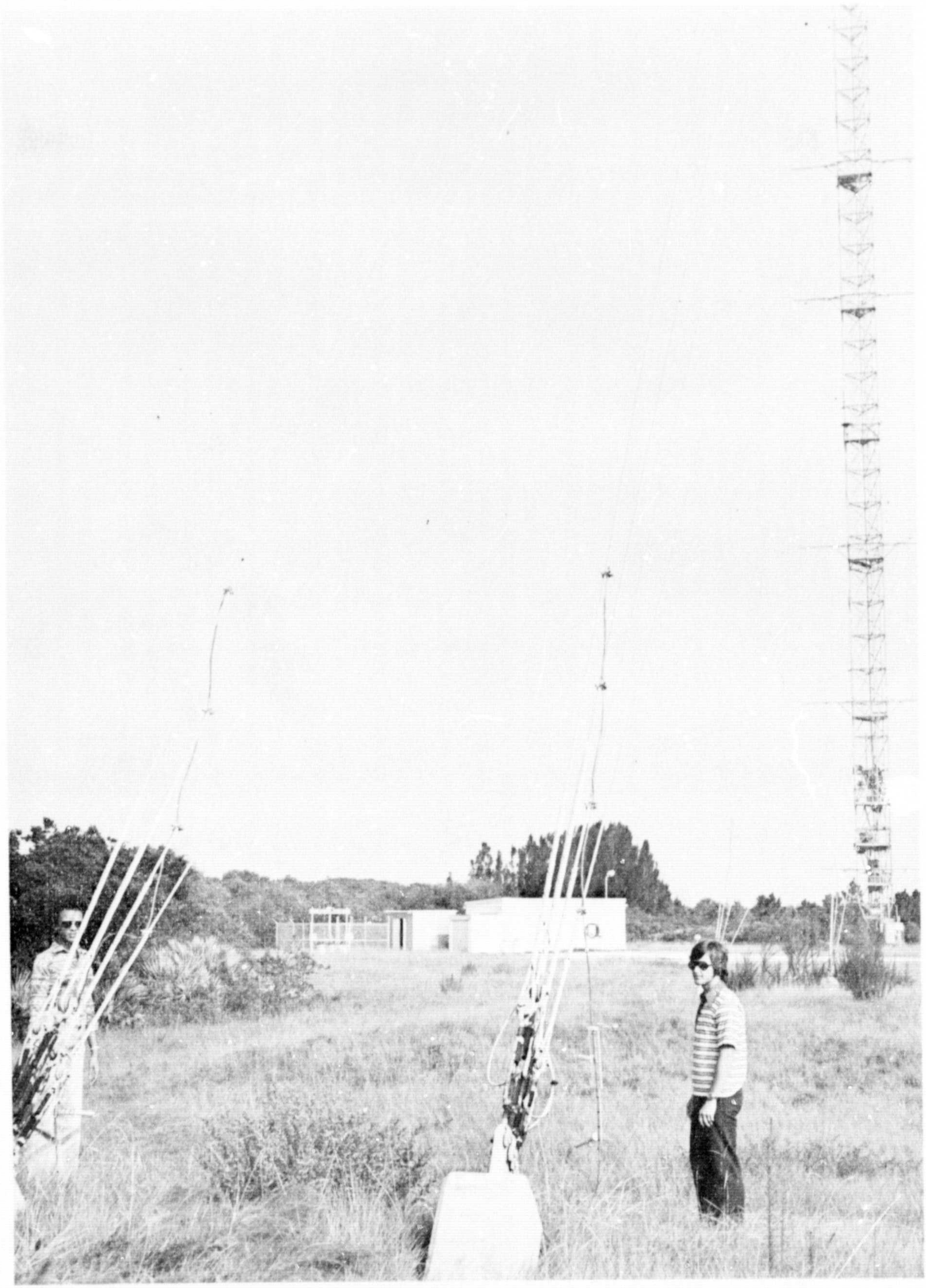


Figure 4b.- 150 meter weather tower from south guy wire base.

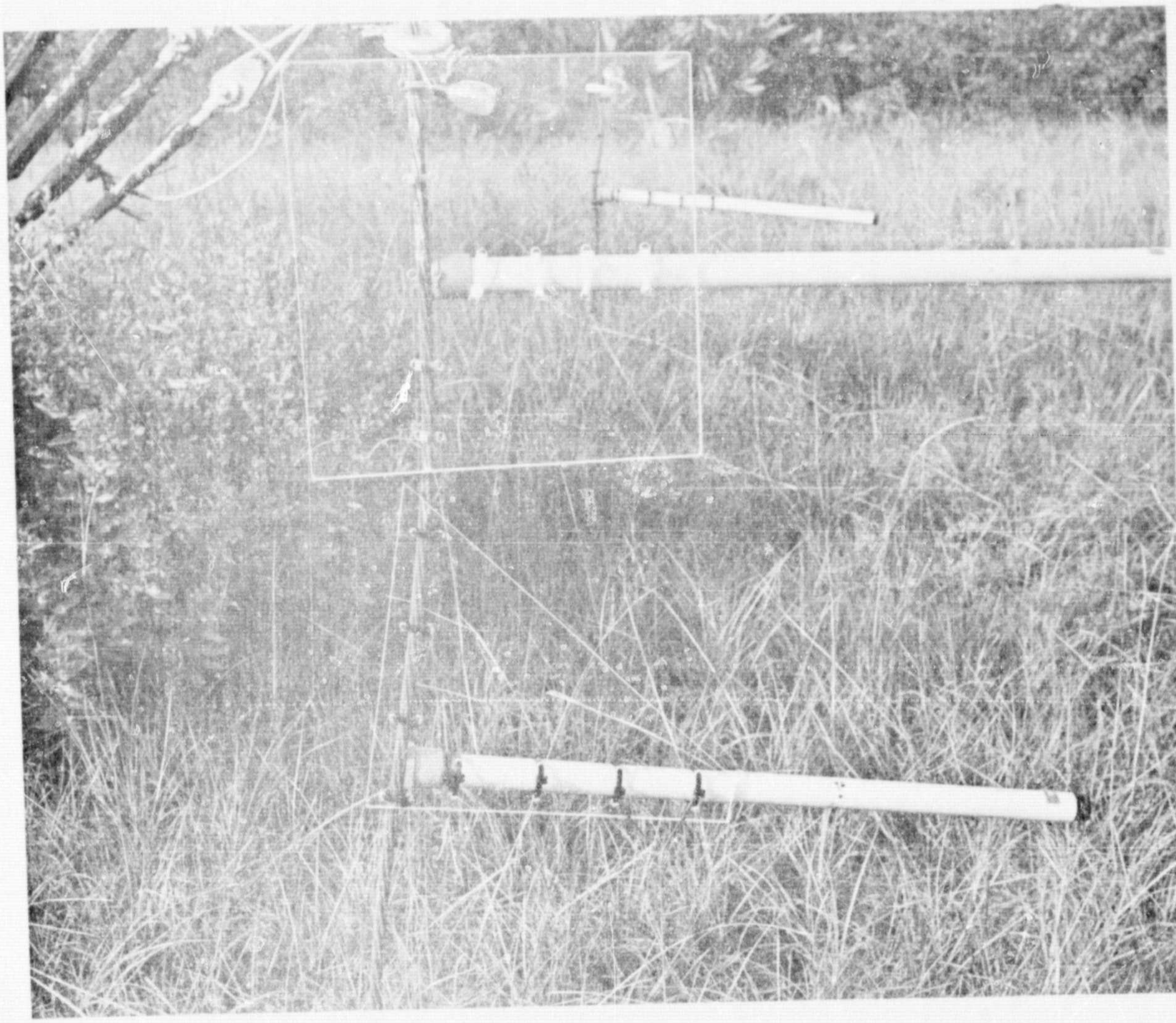


Figure 4c. - Current detectors mounted to guy ground cable.

LIGHTNING INTENSITY TEST

To calibrate the magnetic tape inside the current detector, a test was performed at the Electromagnetics Laboratory at KSC to determine the amount of reference signal erased from the magnetic tape when a known value of current was injected down a test rod. A portable high voltage generator was constructed by IN-TEL-32, based on the design shown in Figure 5. The purpose of this high voltage generator was to simulate lightning currents at low level magnitudes to calibrate the magnetic tape in the current detector.

The configuration of the test setup is shown in Figure 6. The schematic of the test equipment setup is shown in Figure 7. A shielded enclosure was constructed around the current detector to shield out any unwanted magnetic fields from the generator or other sources which might have interferred with those fields produced by the metal conductor.

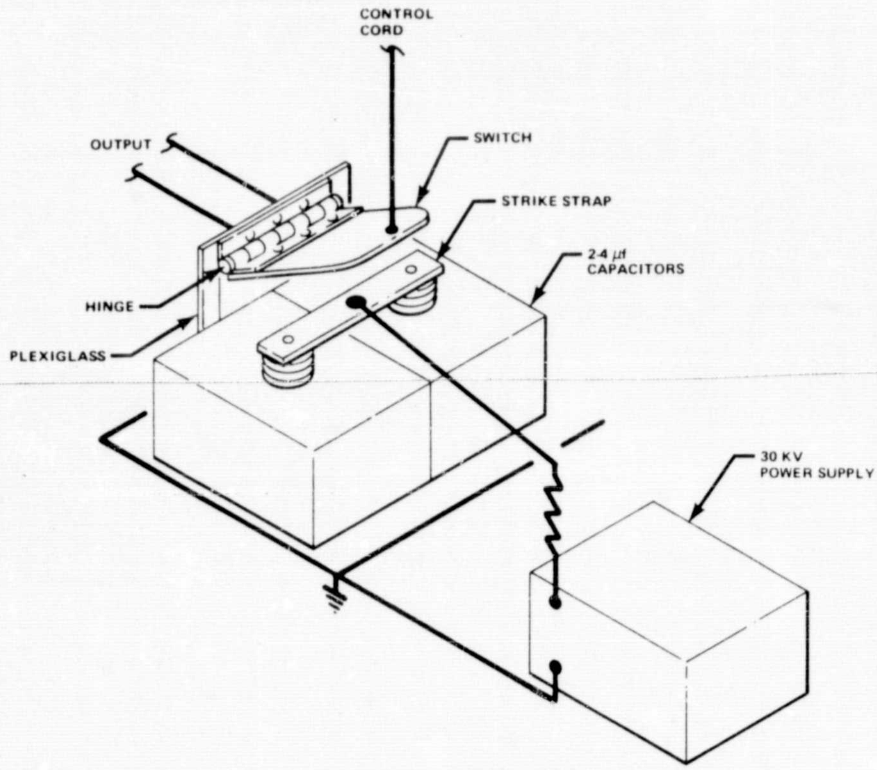


Figure 5.- High voltage generator for SVO Lightning Intensity test.

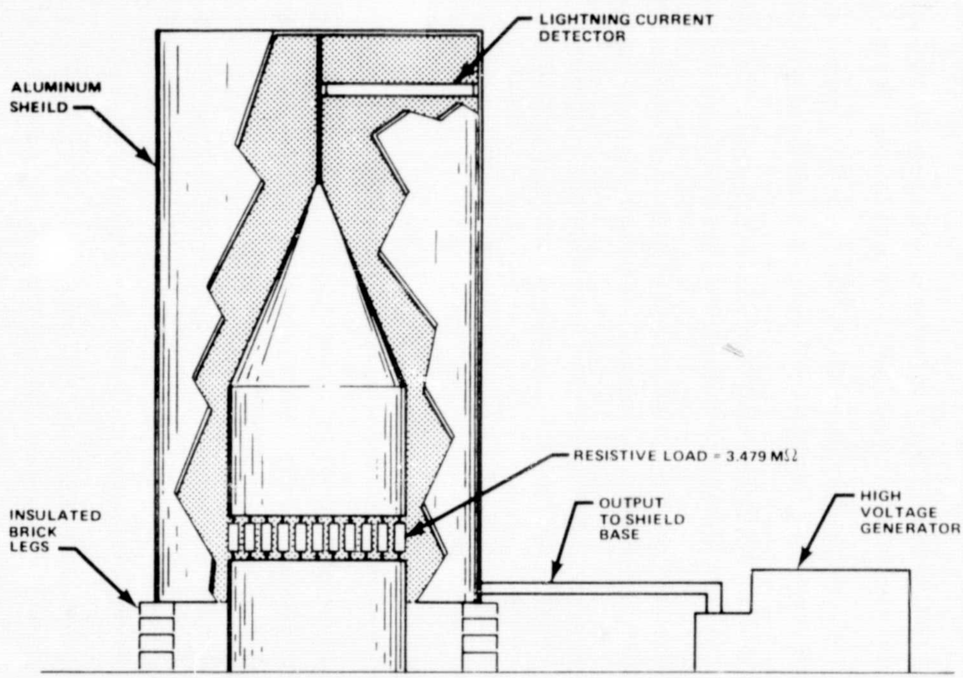


Figure 6.- Lightning intensity test setup.

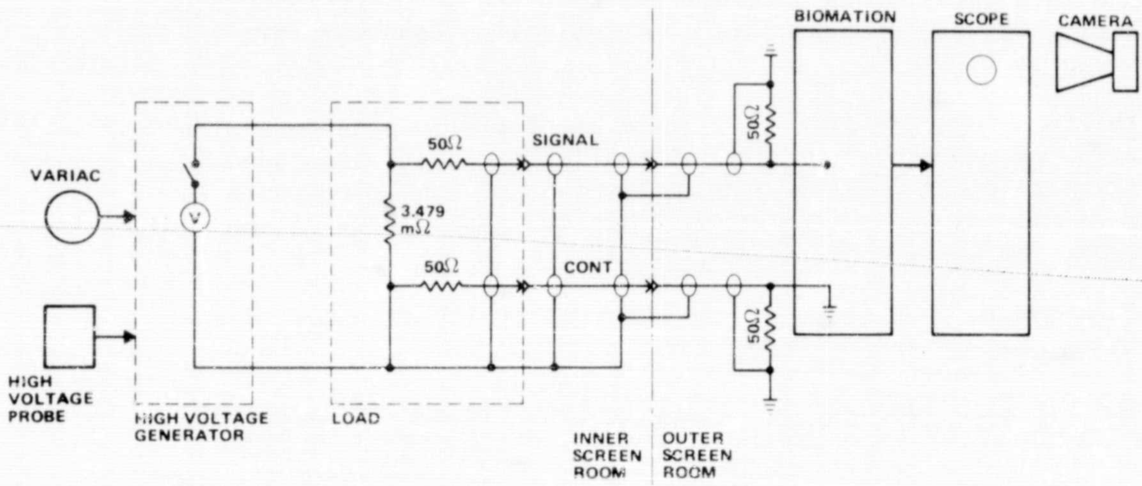


Figure 7.- Lightning intensity test equipment schematic.

Test Equipment

High Voltage Generator
AC Variac
High Voltage Probe and Meter
High Current Load
Oscilloscope
Camera
Biomation Recorder
Lightning Current Detector

Test Procedure

o Using a capacitor bank as the voltage source, various current levels were passed through a 1/4" O.D. test conducting rod and shunt resistor. The voltage waveform was then recorded with a Biomation recorder and subsequently displayed on the oscilloscope for measurement. From this information, the maximum peak current could be calculated.

- o A damped oscillatory waveform was selected so currents of high amplitudes could be achieved. A typical voltage waveform is shown in Figure 8.

- o Thirteen separate test shots were completed to provide a wide range of curent values for calibration purposes. Included in these thirteen test shots were a series of low level tests to determine as accurately as possible the sensitivity of the lightning current detector.

- o An 8 KHz reference signal was recorded on the magnetic tapes to be used in the tests.

- o The magnetic tape was installed in the detector in different configurations to establish if tape positioning was a factor in the amount of reference signal that was erased from the tape.

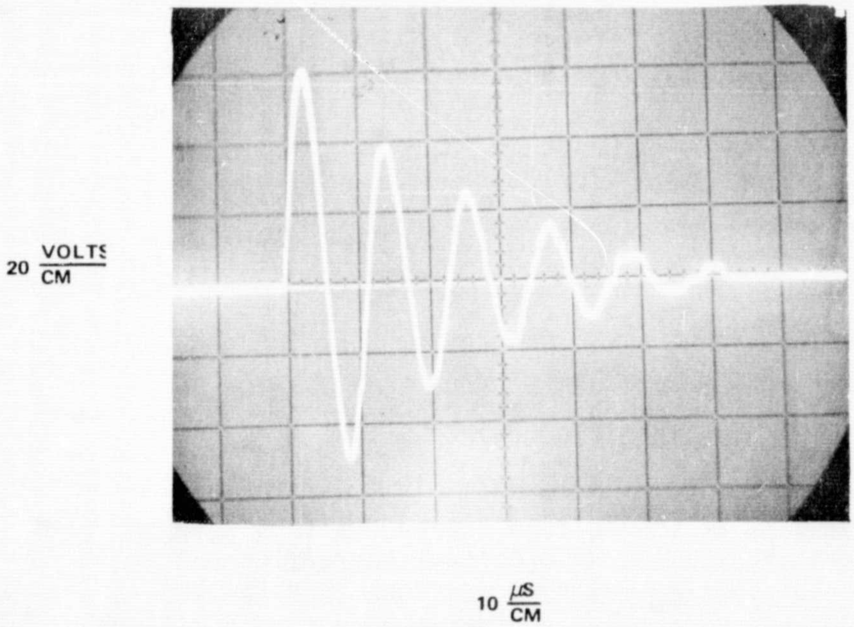
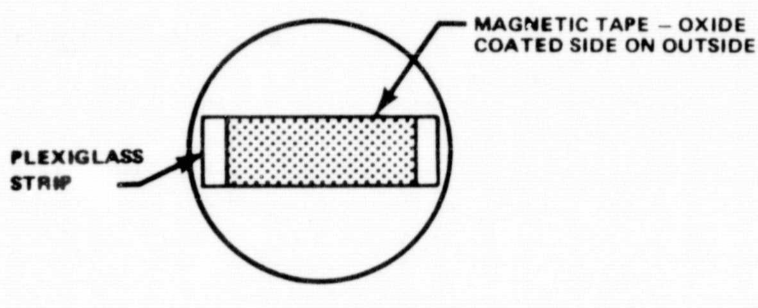


Figure 8.- Typical voltage waveform used for lightning intensity test.

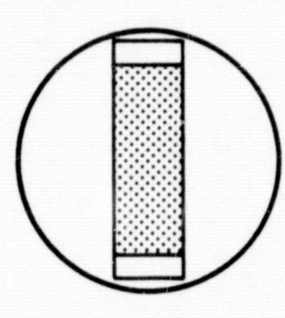
Tests 1, 3, 4, 5, and 8-11 were performed with the magnetic tape lying in the planned, horizontal, flat configuration inside of the PVC tube with the oxide coated side of the tape on the outside of the plexiglass strip (Figure 9). The tape configuration for Test 2 and Test 6 is shown in Figure 10, Test 7 in Figures 11a and 11b, Test 12 in Figure 12, and Test 13 in Figure 13.

The test data is shown in Table I.



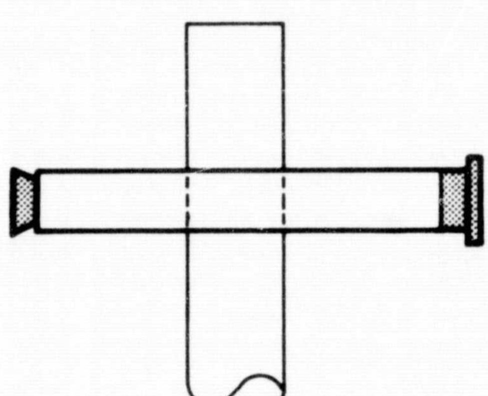
End view of PVC tube

Figure 9.- Magnetic tape in planned, horizontal configuration.



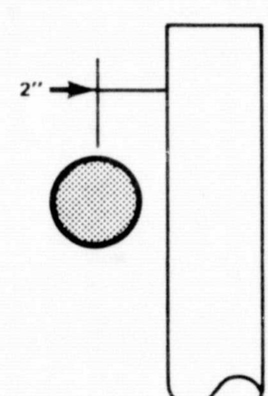
End view of PVC tube

Figure 10.- Magnetic tape in vertical configuration.



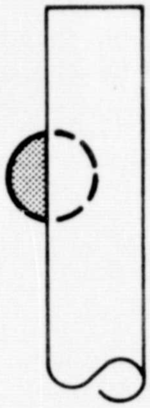
Side view of PVC tube

Figure 11a.- Magnetic tape in side view of PVC tube.



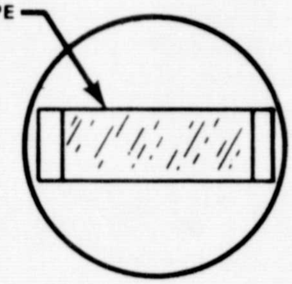
End view of PVC tube

Figure 11b.- Magnetic tape in end view of PVC tube.



End view of PVC tube

Figure 12.- Magnetic tape in off-center configuration.



End view of PVC tube

Figure 13.- Magnetic tape in reversed configuration.

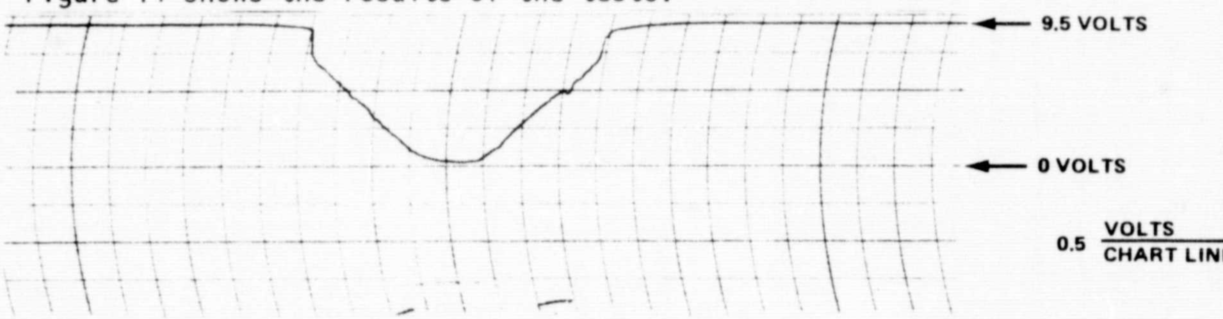
TABLE I

LIGHTNING INTENSITY TEST DATA

LOAD RESISTOR = 3.479 mΩ

TEST NO.	DATE	HIGH VOLTAGE KV	RECORDED PEAK VOLTAGE V	CALCULATED CURRENT A	PHOTOGRAPH HORZ. μs/div	PHOTOGRAPH VERT. V/div	REMARKS
1.	6-26	6 KV	19V	5,461A	10 μs/div	5V/div	6 dB
2.	6-26	5 KV	17V	4,886A	10 μs/div	10V/div	6 dB
3.	6-26	10 KV	34V	9,772A	10 μs/div	10V/div	6 dB
4.	6-26	15 KV	50V	14,372A	10 μs/div	20V/div	6 dB + 6 dB
5.	6-26	20 KV	62V	17,821A	10 μs/div	20V/div	6 dB + 6 dB
6.	6-26	20 KV	62V	17,821A	10 μs/div	20V/div	6 dB + 6 dB
7.	6-26	20 KV	62V	17,821A	10 μs/div	20V/div	6 dB + 6 dB
8.	7-6	1 KV	3.8V	1,092A	10 μs/div	1V/div	6 dB
9.	7-6	2 KV	7.6V	2,184A	10 μs/div	1V/div	6 dB
10.	7-6	3 KV	11.2V	3,219A	10 μs/div	2V/div	6 dB
11.	7-6	4 KV	14.4V	4,139A	10 μs/div	2V/div	6 dB
12.	7-6	5 KV	18.4V	5,289A	10 μs/div	2V/div	6 dB
13.	7-6	5 KV	18.8V	5,404A	10 μs/div	2V/div	6 dB

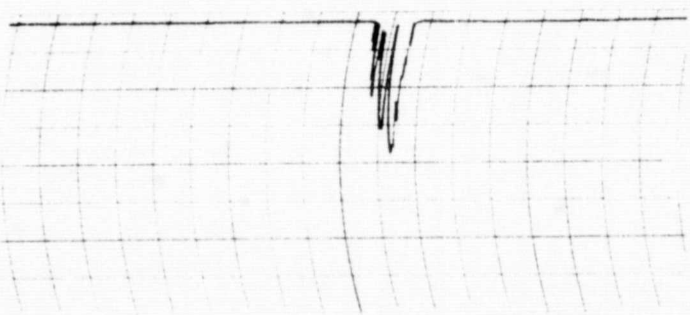
Upon completion of the tests, the magnetic tapes from all the tests were spliced together, each separated by a section of the reference tape for comparison, and their results recorded on the Brush recorder. Figure 14 shows the results of the tests.



TEST 1

BRUSH RECORDER SPEED = 25 $\frac{MM}{SEC}$

TAPE RECORDER SPEED = $\frac{15}{16}$ IPS

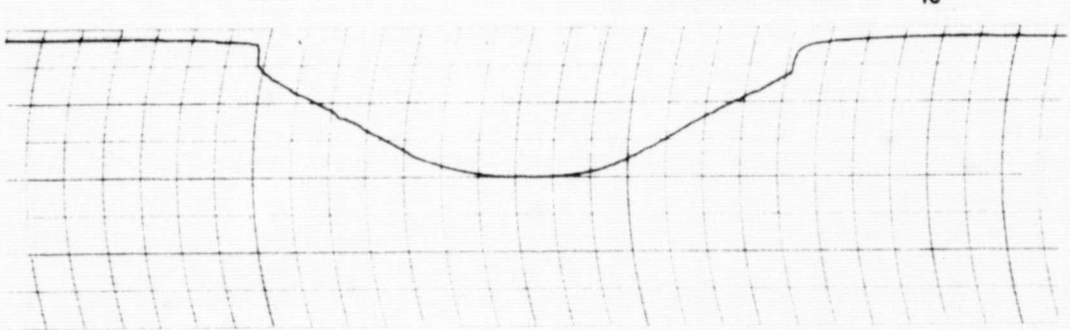


TEST 2

BRUSH RECORDER SPEED = 5 $\frac{MM}{SEC}$

TAPE RECORDER SPEED = $\frac{15}{16}$ IPS

0.5 VOLTS/CHART LINE



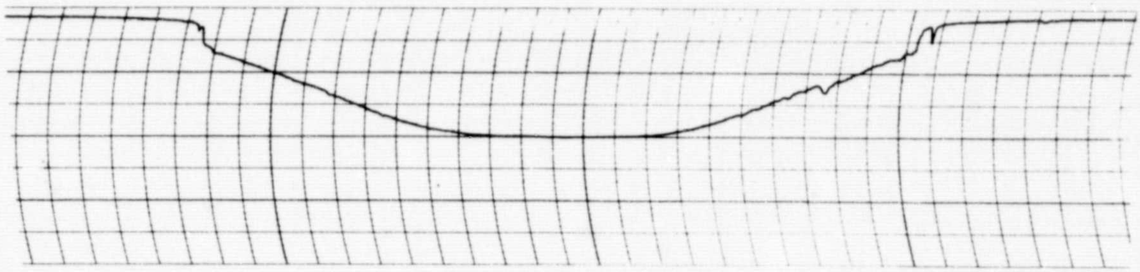
TEST 3

BRUSH RECORDER SPEED = 25 $\frac{MM}{SEC}$

TAPE RECORDER SPEED = $\frac{15}{16}$ IPS

0.5 VOLTS/CHART LINE

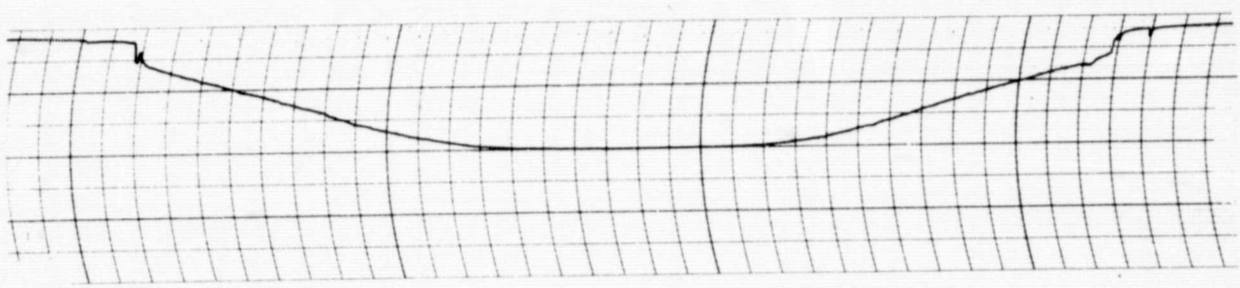
Figure 14.- Brush recorder results of Lightning Intensity test.



TEST 4

BRUSH RECORDER SPEED = 25 $\frac{MM}{SEC}$ 0.5 $\frac{VOLTS}{CHART\ LINE}$

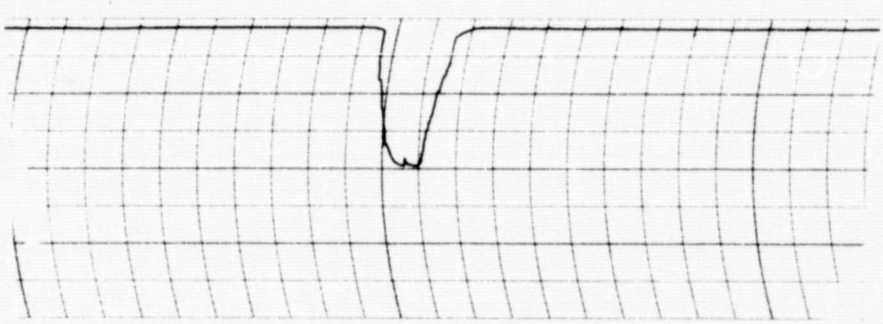
TAPE RECORDER SPEED = $\frac{15}{16}$ IPS



TEST 5

BRUSH RECORDER SPEED = 25 $\frac{MM}{SEC}$ 0.5 $\frac{VOLTS}{CHART\ LINE}$

TAPE RECORDER SPEED = $\frac{15}{16}$ IPS

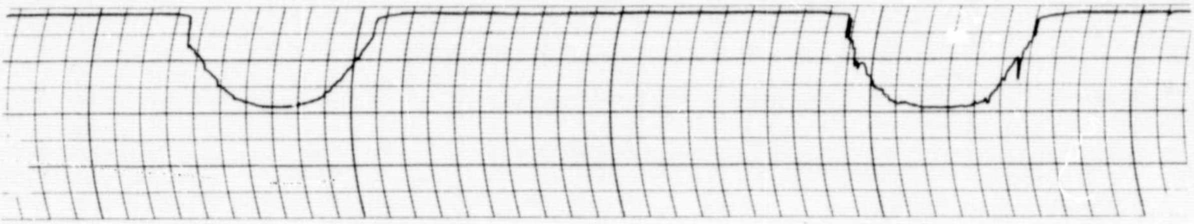


TEST 6

BRUSH RECORDER SPEED = 5 $\frac{MM}{SEC}$ 0.5 $\frac{VOLTS}{CHART\ LINE}$

TAPE RECORDER SPEED = $\frac{15}{16}$ IPS

Figure 14.- Brush recorder results of Lightning Intensity test.

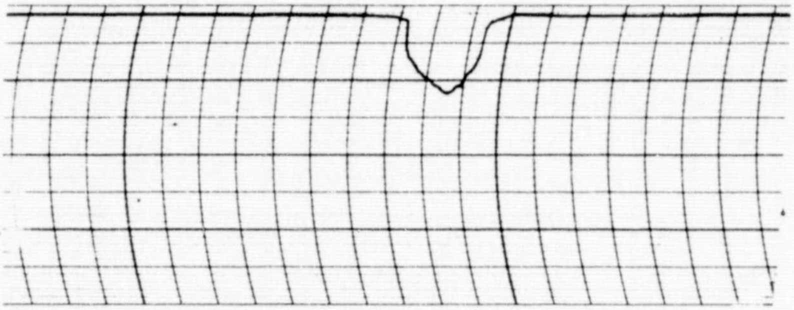


TEST 7

BRUSH RECORDER SPEED - 5 $\frac{MM}{SEC}$

TAPE RECORDER SPEED - $\frac{15}{16}$ IPS

0.5 $\frac{\text{VOLTS}}{\text{CHART LINE}}$



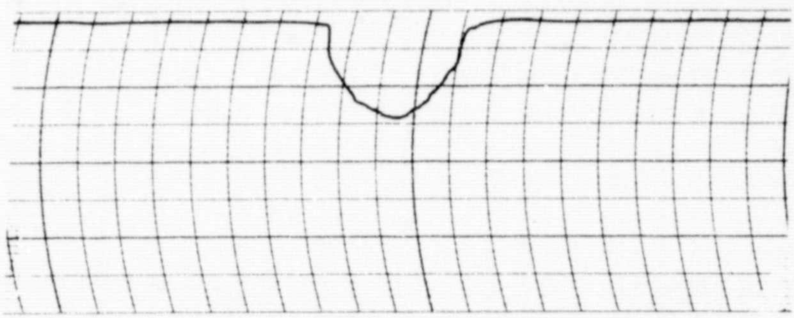
0.5 $\frac{\text{VOLTS}}{\text{CHART LINE}}$

TEST 10

BRUSH RECORDER SPEED - 25 $\frac{MM}{SEC}$

TAPE RECORDER SPEED - $\frac{15}{16}$ IPS

Figure 14.- Brush recorder results of Lightning Intensity test.

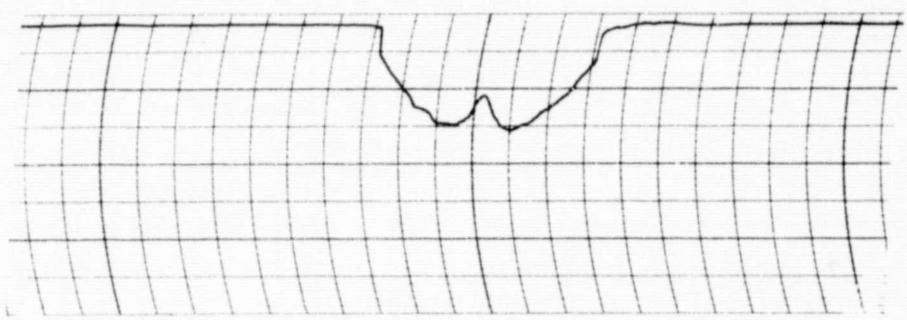


0.5 $\frac{\text{VOLTS}}{\text{CHART LINE}}$

TEST 11

BRUSH RECORDER SPEED - 25 $\frac{\text{MM}}{\text{SEC}}$

TAPE RECORDER SPEED - $\frac{15}{16}$ IPS

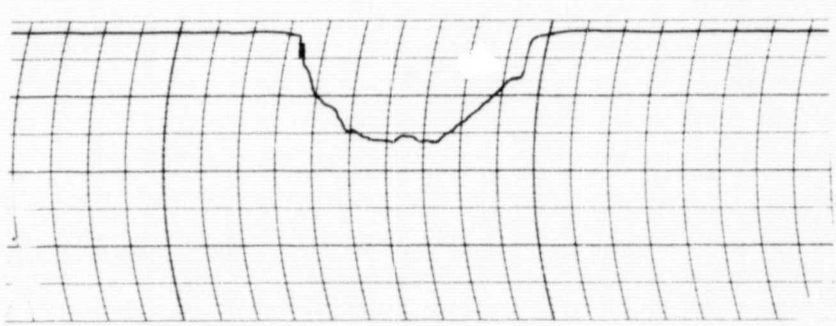


0.5 $\frac{\text{VOLTS}}{\text{CHART LINE}}$

TEST 12

BRUSH RECORDER SPEED - 25 $\frac{\text{MM}}{\text{SEC}}$

TAPE RECORDER SPEED - $\frac{15}{16}$ IPS



0.5 $\frac{\text{VOLTS}}{\text{CHART LINE}}$

TEST 13

BRUSH RECORDER SPEED - 25 $\frac{\text{MM}}{\text{SEC}}$

TAPE RECORDER SPEED - $\frac{15}{16}$ IPS

Figure 14.- Brush recorder results of Lightning Intensity test.

For calculating the distance away from the conducting rod that the reference signal was affected by the magnetic fields, the following formular was used:

$$r = \frac{T \times S}{2} \quad . . . . (2)$$

where

r = distance on magnetic tape the reference signal was affected (inches)

T = total period the reference signal was affected (sec)

S = tape recorder speed (ips)

The test results and calculations for r are included in the following table:

Test No.	T (Sec)	I (Amps)	S (ips)	Brush recorder speed (mm/sec)	r (inches)
1	1.60	5461	15/16	25	0.75
2	1.00	4886	15/16	5	0.47
3	2.86	9772	15/16	25	1.34
4	4.70	14372	15/16	25	2.20
5	6.24	17821	15/16	25	2.92
6	2.20	17821	15/16	5	1.03
7	15.20	17821	15/16	5	7.12
8	negligible	1092	15/16	25	no effect
9	negligible	2184	15/16	25	no effect
10	0.52	3219	15/16	25	0.24
11	0.80	4139	15/16	25	0.37
12	1.28	5289	15/16	25	0.60
13	1.36	5404	15/16	25	0.64

A plot of the relationship between I vs. r is shown in Figure 15. These points plotted are from results of tests 1, 3, 4, 5, and 8-13 since they all had the same tape configuration.

Since these experimental points describe a linear relationship between I and r, a linear curve fit program can be computed to represent these points by a straight line, the form of the equation $y = a_1 x + a_0$, where a_1 and a_0 are constants, and x and y are the variables.

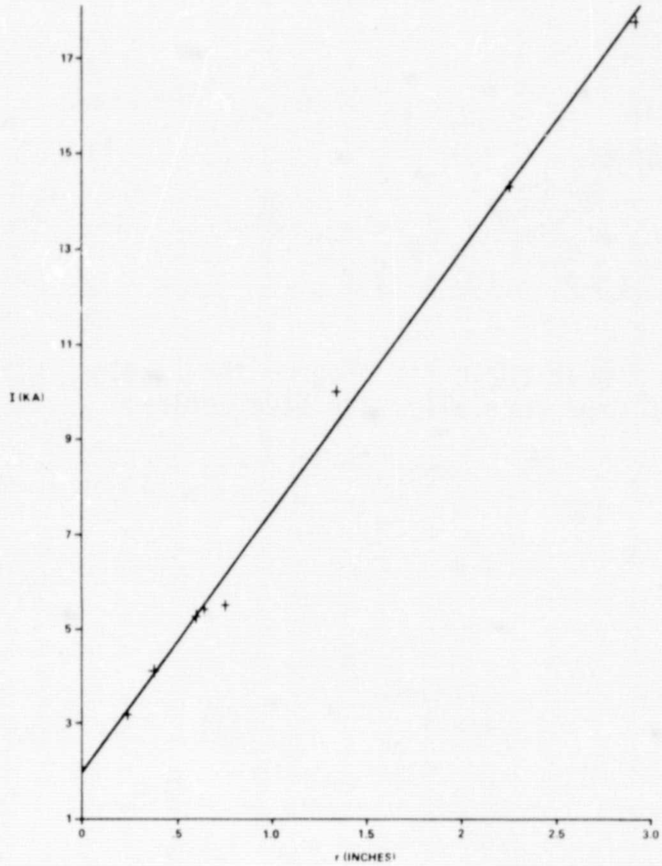


Figure 15.- Injected current through test conducting rod as a function of distance reference signal erased on magnetic tape.

The purpose of this program is to find the constants a_1 and a_0, which give the closest agreement between the experimental data and the equation $y = a\,x + a_0$. The technique used is linear regression by the method of least squares. When all data pairs, $(x_i, y_i, i = 1,..,n)$, have been input, the regression constants a_1 and a_0 may be calculated. A third value may also be found, the coefficient of determination, R^2. The value of R^2 will lie between 0 and 1 and will indicate how closely the equation fits the experimental data: the closer R^2 is to 1, the better the fit.

Equations: $y = a_1 x + a_0$ . . . . (3)

Regression Constants:

(n = Number of data points)

$$a_1 = \frac{\Sigma xy - \dfrac{\Sigma x \Sigma y}{n}}{\Sigma x^2 - \dfrac{(\Sigma x)^2}{n}} \quad . . . . . (4)$$

$$a_0 = \frac{\Sigma y}{n} - a_1 \frac{\Sigma x}{n} \quad . . . . . (5)$$

Coefficient of determination:

$$R^2 = \frac{\left[\Sigma xy - \frac{\Sigma x \Sigma y}{n} \right]^2}{\left[\Sigma x^2 - \frac{(\Sigma x)^2}{n} \right] \left[\Sigma y^2 - \frac{(\Sigma y)^2}{n} \right]} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

The results of the linear curve fit program for I, along with those values for I found experimentally, are given below:

$a_1 = 5534.43$

$a_o = 1909$

$R^2 = 0.9963$

r (Inches)	I (meas) (Amps)	I (calc) (Amps)	% Diff. from Measured Values
0.24	3219	3237	0.6
0.37	4139	3985	-3.7
0.60	5289	5230	-1.1
0.64	5404	5437	0.6
0.75	5461	6060	9.9
1.34	9772	9329	-4.5
2.20	14372	14102	-1.9
2.92	17821	18097	1.5

From the computed values for a_1 and a_o, any value of I can be found once r is known by substituting into the equation

$$I = a_1(r) + a_o \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

PROBLEMS AND CONSIDERATIONS

- o One problem encountered with the present equipment configuration is moisture developing inside of some of the detector tubes.
- o Heat buildup inside of the tube might also pose a problem to the recorded reference signal on the magnetic tape, but no long duration tests have been completed yet.
- o The plexiglass strip mounted inside of the detector tube had to be modified to alleviate problems encountered with low level lightning strikes to the tower. The end of the plexiglass strip mounted flush against the end cap had to be rounded at the end to prevent the magnetic tape from kinking. These kinks in the

tape caused gliches in the reference signal which interferred with the calculation for a low level lightning strike.

- The thickness of the end cap prevents the magnetic tape from lying flush against the guy wire strap so this distance must be taken into consideration when calculating I. The thickness of the end cap used in the lightning intensity test was 3/16".

- Mounting the detectors on various shaped conductors, i.e., channel iron, three inch round pipe, etc. could produce different results due to the configurations of the conductors.

RECORDING EQUIPMENT AND PROCEDURE

Recording Equipment

1/4" Scotch 150 Magnetic Tape on 7" reels
Wollensak Single Channel Tape Recorder
Hewlett-Packard audio generator 200 C.D.
Brush 2 Channel Recorder
Rectifier Circuit (Figure 16)

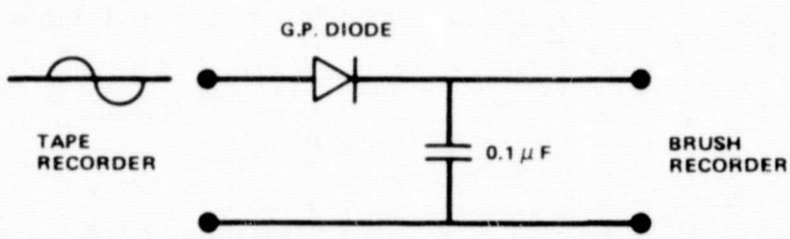


Figure 16.- Rectifier circuit.

Recording Procedure

The reference signal recorded on the magnetic tape was an 8 KHz sine wave which was rectified and filtered prior to being read by the strip chart recorder (Figure 16). This particular frequency value seemed to require less filtering in its conversion to DC for easier use by the brush recorder. An output of 9.5 volts was decided upon as the best value for the recording equipment being used.

The reference signal was recorded on both tracks of a full reel of tape to provide a check for gliches that might appear on the tape. A glich on the reference tape will not appear on both tracks, but an erasure of the reference signal due to the presence of a magnetic field will appear on both sides.

The speed of the tape recorder on playback of the reference signal can be varied to change the frequency of the reference signal, however, this does not affect the output of the rectified signal.

ROGOWSKI COIL - FLASHBULB UNIT

The purpose of the Rogowski coil - flashbulb unit is to provide, upon inspection, a visual indication of a lightning strike to the tower. This alleviates the problem of removing the magnetic tapes after every storm to check for a lightning strike. Two flashbulb units are mounted to guy ground straps of the tower directly above the lightning detector mounts. These two coils provide redundant checks in case of failure in one unit. Lightning current injected down the guy ground cable will induce a voltage in the coil leads and trigger the attached flashbulb.

Current Sensors[2]

The Rogowski coils used for this installation sense the magnetic field strength around a path enclosing a current carrying conductor. Their principle of operation is shown on Figure 17. A current carrying conductor sets up a magnetic field strength, H, expressed in amperes per meter, in the surrounding region. An elementary one-turn loop conductor placed in the field will link magnetic flux

$$\phi = A \cdot H \quad \ldots\ldots\ldots\ldots\ldots \quad (8)$$

where A equals the area of the loop. The voltage induced in the loop will be

$$e = \frac{d\phi}{dt} \quad \ldots\ldots\ldots\ldots\ldots \quad (9)$$

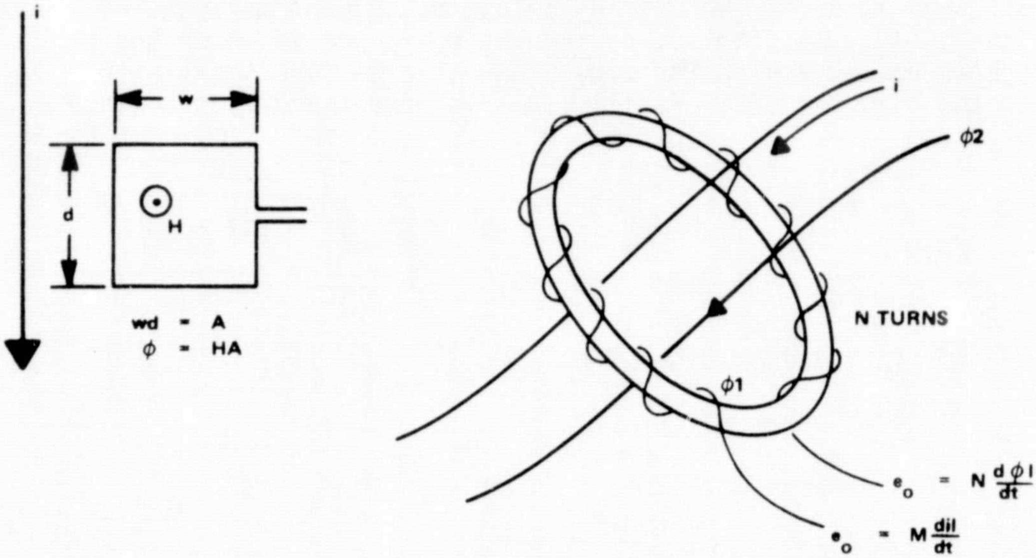


Figure 17.- Elementary Rogowski coil winding.

A series of loops encircling the conductor will have a voltage induced in each loop and the total voltage induced in all loops will equal the voltage developed in the entire coil. If each loop evaluates the field strength H at a point, the entire assembly of loops will evaluate the total field strength around the current carrying conductor. Since the line integral of field strength around a conductor is equal to the current in the conductor, the voltage developed at the terminals of the coil will be proportional to the current flowing through the conductor.

$$e_o \propto \frac{d}{dt} \left[\quad H \cdot d \quad \right] \quad . \; . \; . \; . \; . \; . \; . \; (10)$$

$$H \cdot d = i \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (11)$$

$$e_o \propto \frac{di}{dt} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; (12)$$

The magnitude of the output voltage is proportional to the geometry of the coil as well as to the rate of change of current through the plane of the coil. The simplest configuration is one in which the coil is of circular geometry with the dimensions of each loop small with respect to the diameter of the coil. In this case the output voltage of the coil is:

$$e_o = \frac{(2 \times 10^{-9}) NA}{r_m} \frac{di}{dt} \text{ volts} \quad . \; . \; . \; . \; . \; (13)$$

where

r_m = Mean radius of coil -cm

N = Number of turns

A = Cross sectional area of each turn - cm^2

$\frac{di}{dt}$ = Rate of change of current through down conductor-amp/sec

Calibration of Coils

The Rogowski coil - flashbulb unit configuration is shown in Figures 18a and 18b. The current sensing coil calibration is dependent upon the di/dt term of the lightning current so, therefore, a representative value for the risetime of an average Florida lightning stroke had to be chosen. The two current sensing coils used for this project are designed to trigger the attached flashbulb when a peak current of 600 amperes with a one usec risetime for one coil and 300 amps/usec for the other coil is injected through the guy ground cable. These current values were designed because of the 2000 ampere sensitivity of the lightning current detectors. The lightning current detectors are capable of measuring current values as low as 2000 amperes, but due to the numerous parallel paths that current will travel along the tower to ground, a low level strike may not indicate more than 2000 amperes on any one of the detectors. Also, since nearby lightning strikes can induce voltages and currents in wires, a flashbulb may go off due to an induced current injected down the guy wire if the di/dt value for the coil was chosen too low. The Rogowski coils will provide adequate information to determine the approximate magnitude of the lightning current in the event of a low level strike.

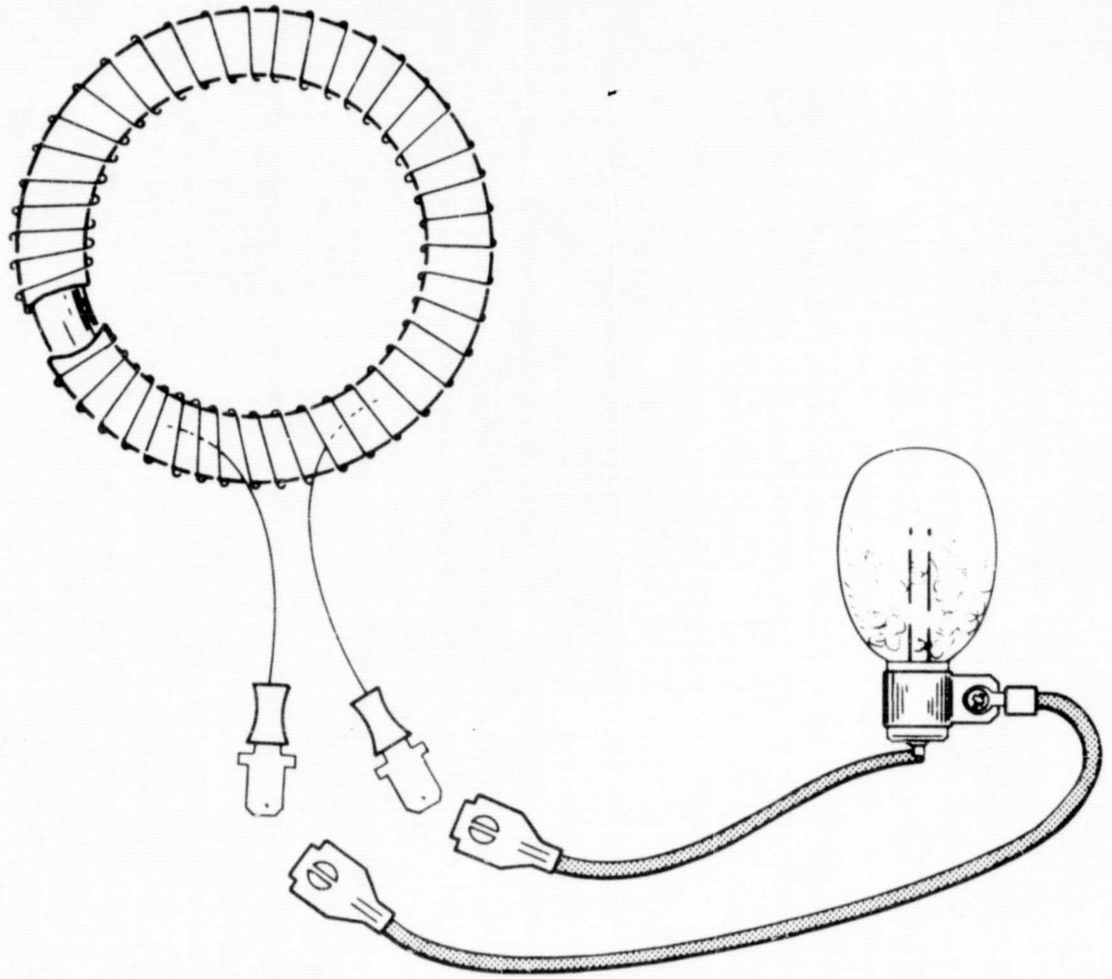


Figure 18a.- Rogowski coil - flashbulb unit configuration.

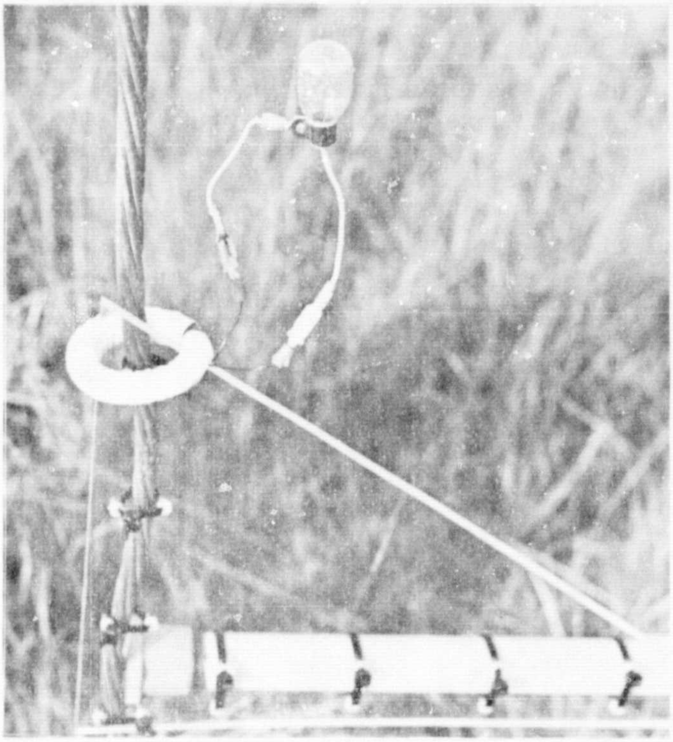


Figure 18b.- Rogowski coil - flashbulb unit mounted to guy ground cable at South guy wire base of 150 meter weather tower.

Material Description and Construction

The wire wrapping of the Rogowski coils used for this installation is wound around a core of flexible tygon tubing (3/8" O.D.). The two ends of the tygon tubing are joined together by a nonconducting plug which permits the coil core to be separated for installation on a conducting wire or cable. The mean diameter of the coil is 5 cm and the flashbulb attachment is rated at 3 to 45 volts. The coils are wrapped in a shielded enclosure which both shields against unwanted electrostatic fields and suppresses undesired magnetic fields. Twenty gage solid wire is used for the wire wrapping, and teflon tape is used to protect the entire coil from moisture and corrosion.

FIELD RESULTS OF CURRENT DETECTORS

On July 19, 1976 at 130007 EDT, a cloud-to-ground lightning stroke was observed, from two separate locations, in the vicinity of the 150 meter weather tower. Upon inspection of the tower afterwards, the flashbulb of the Rogowski coil had been initiated, indicating a possible strike to the tower. At this time, only one current detector and one coil were installed at the south guy wire base of the tower. The brush recorder results of this tape are shown on Figure 19. The erasure of the reference signal on the magnetic tape indicated a peak current of 13,860 amperes traveled down the guy ground cable on that particular guy wire leg. Based on assumptions of the percentage of current down the major paths of the tower to ground, the total peak current of the lightning stroke was approximated at 189,000 amperes. This was also assuming that the value of current down this particular guy ground cable was representative of all the other guy ground cables.

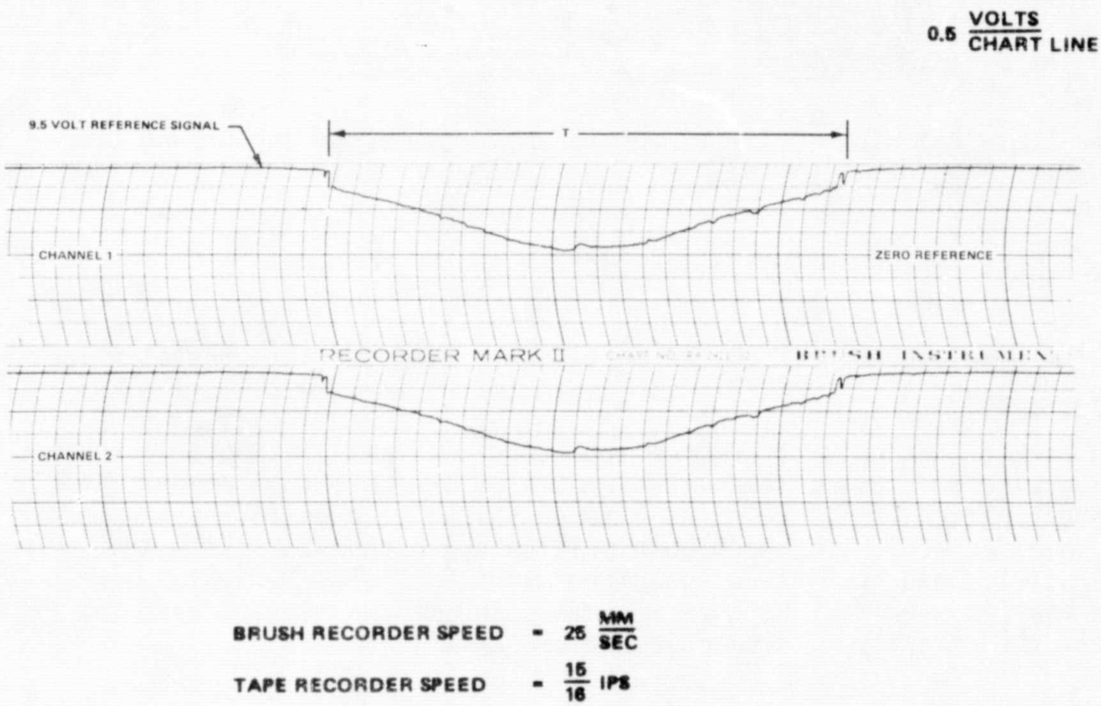


Figure 19.- Brush recorder results from lighting current detector of 7/19/76 lightning flash to 150 meter weather tower.

On Monday August 16, 1976, the weather tower was visually inspected, and it was noted that the flashbulb of the Rogowski coil mounted to the south guy wire leg had been initiated. A check with the KSC weather office indicated that the wind data from the tower became erroneous after 1430 on Saturday August 14, 1976.

All the magnetic tapes were removed from the detectors mounted to the tower and their results were evaluated. The readings from the guy ground cables indicated a total peak current from the lightning strike of 85,600 amperes. The readings from the top of the tower were inconclusive and did not match those of the guy wires. Since the three detectors on top of the tower were mounted to channel iron supports and not cables, further tests need to be performed on this type of a configuration. It was also noted that the LEA dissipation array ground wire had been severed in two places from the lightning flash.

The assumptions used for calculating the current distribution down the 150 meter tower are:

80% down outer guy wires
17% down inner guy wires
3% down tower

For outer guy wires:

55% down guy ground cable
45% down concrete support

MOUNTING AND INSTALLATION CONSIDERATIONS

Some mounting and installation considerations are listed below:

a. The PVC tube should be mounted flush to the wire or cable under consideration to bring the magnetic tape inside the tube as close as possible to the cable.

b. End caps with small base widths should be used for the same reason as stated in a above.

c. Detectors should be mounted against cables or conductors of relatively small diameters, not much larger than the diameter of the detector itself (1"). Otherwise the end cap of the detector would not sit flush against the middle surface of the conductor due to the radius of curvature of the conductor.

d. The detector should be mounted perpendicular to the conducting cable to obtain the most accurate data.

e. The detector should be oriented so that it is not close to other conducting cables to prevent interference from undesired magnetic fields.

f. The magnetic tape inside of the PVC tube should lie in a flat, horizontal position relative to the ground for the most accurate data.

FUTURE MODIFICATIONS OR IMPROVEMENTS

a. The mounting fixtures for the current detectors could be modified to provide less wind resistance to prevent the entire fixture from rotating around the wire or cable. One possiblility would be to drill holes in the plexiglass mounts.

b. To prevent condensation from collecting inside of the tube, one solution could be to drill one or more small holes in the bottom of the PVC tube.

c. Calibration tests need to be performed using channel iron and three inch pipe as conductors.

CONCLUDING REMARKS

The results of this project indicate that the lightning current detectors will provide the capability for monitoring lightning current magnitudes of the 150 meter weather tower. Good correlation was achieved between experimental measurements received from the lightning intensity tests and those calculated from the linear curve fit program. Since these current detectors are passive devices requiring no external power, they are economical to use and easy to install and remove for calibration. No visual evidence to date has indicated that exposure to the weather causes any adverse effects to the magnetic tape installed inside of the detector tube. One recommendation to consider would be to conduct a calibration test of the current detector on a large diameter pipe or channel iron support to determine if the results vary from those obtained utilizing a small diameter cable. The Rogowski coil - flashbulb units provide an adequate check of a lightning strike to the tower and have performed satisfactorily in the field to date. The successful performance of the lightning current detector during the lightning intensity test and subsequent performance during the 1976 thunderstorm season at KSC verifies that the detector developed for the 150 meter tower is appropriate and useful.

APPENDIX A

150 Meter Weather Tower Lightning Strikes

A summary of the total number of strikes to the 150 meter tower for the past 12 years is included below.

Year	Total strikes per Year	April	May	June	First half of July
1965	3	0	1	1	0
1966	4	0	1	2	0
1967	0	0	0	0	0
1968	2	0	0	1	0
1969	2	0	0	0	0
1970	1	0	0	0	0
1971	3	0	0	2	0
1972	3	0	0	2	0
1973	0	0	0	0	0
*1974	3	0	0	1	0
1975	1	0	0	0	0
1976	2 (to date)	0	0	0	0

* The LEA dissipation array was installed on the 150 meter weather tower on June 21, 1974.

REFERENCES

1. Uman, Martin A.; Understanding Lightning. Bek Technical Publications, Inc., 1971.

2. Fisher, Frank A.; Lightning Monitoring Instrumentation for Mobile Service Structure. General Electric Company, 1972.